§9. Achievement of Higher Plasma Stored Energy by 106GHz ECH Power Injection to High-Density NBI Plasmas

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One of the advantages of applying 106.4GHz ECH power is its high X-mode cut-off density, 7×10^{19} m^{-3}, which is twice higher than O-mode cut-off of 53.2GHz, 3.5×10^{19} m^{-3} at the same magnetic field 1.9T at plasma axis. In helical systems such as CHS and LHD, plasmas are routinely generated by ECH power. According to the object of experiment, the plasmas are sustained by ECH power and/or additional NBI power. The central electron density, n_{e0}, of plasmas sustained by NBI power often exceeds the cut-off density of 53.2GHz ECH power. Then applying 106.4GHz power to NB-heated plasmas, high electron temperature and high density can be compatible that results in higher plasma stored energy.

A high power heating experiment was performed to confirm the possibility of extending plasma parameter to high density with higher temperature by applying all the heating devices; 53.2GHz and 106.4GHz ECH's and two NBI's. As is seen in Fig. 1, in the experiment plasmas are generated by simultaneous power injection, from 20ms to 60ms, of 226kW 53.2GHz power in O-mode and 173kW 106.4GHz power in X-mode. The magnetic field on the magnetic axis is 1.9T for fundamental and second harmonic resonance heating. Just in the same timing of 20ms, gas fueling is started and kept until 90ms to sustain high-density plasma. Two NB's (NBI#1:700kW, NBI#2:600kW) are injected just after the plasma generation, from 23ms to 93ms.

The interferometer suffers frequent fringe-jumps at density range higher than 4×10^{19} m^{-3} then it could not work for the experiment. Thomson-scattering (TS) measurement measures electron density distribution. However the calibration for the absolute value is not sufficient then the measured density has ambiguity within 30%.

The plasma stored energy increases almost linearly with time until about 40ms and reaches 4.0kJ. Although after that the increase of the stored energy saturates a little, it reaches the maximum value of 4.4kJ. In the figure, electron temperature and density measured with TS distributions at the times 30ms, 45ms, 60ms and 70ms are also plotted. At the early phase of plasma duration, t=30ms, electron temperature at the magnetic axis T_{e0} exceeds 1.5keV at n_{e0} of higher than 2×10^{19} m^{-3}. Even with n_{e0} higher than 3.5×10^{19} m^{-3}, the cut-off density of fundamental O-mode of 53.2GHz power, T_{e0} is kept at about 1keV as seen in TS data at 45 and 60ms. This means that although the 53.2GHz power is reflected at the cut-off and can not contribute to plasma heating, 106.4GHz power effectively heats the high density NBI plasma.

It should be noted that after the termination of ECH power injection, NBI's can not sustain the high density plasma. Thus, this experiment demonstrated that 106.4GHz power can extend CHS plasma parameter to high density and high temperature regime.

In the experiment, power dependence of stored energy was also investigated. The injection power of 53.2GHz was varied from 110kW to 226kW. Those of 106.4GHz, NBI#1, NBI#2 were fixed at 173kW, 700kW and 600kW, respectively. Each heating devices was switched on or off, and the combination of them was changed. The tendency of the stored energy generally obeys a square root of total injected power but the effect of additional 106.4GHz power is distinctly seen in Fig. 2. In the case without NBI's, though the injected power of 53.2GHz and 106.4GHz are nearly equal, the stored energy by 106.4GHz power is much higher than that by 53.2GHz power. The difference comes from the change of available density in those cases.

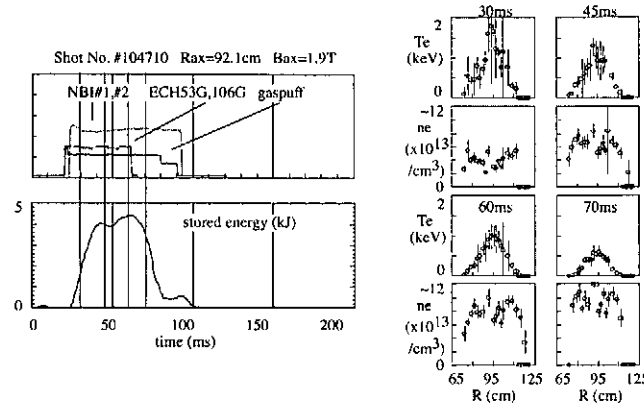

Fig.1 Time sequence and T_e, n_e distribution measured with TS of the shot that marked the highest stored energy 4.4kJ in the high power heating experiment.

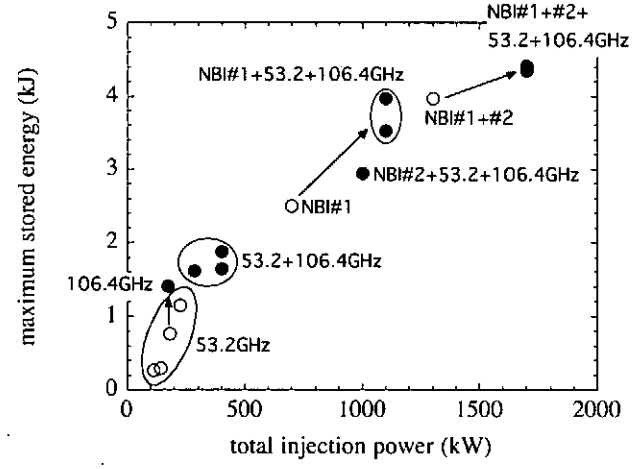

Fig.2 Dependence of the maximum stored energy achieved during plasma shots with various combination of heating devices. Open circles denote the shots without 106.4GHz power and the closed ones with the 106.4GHz power.